e→μ 12/14/94

CEBAF Program Advisory Committee Nine Proposal Cover Sheet

This proposal must be received by close of business on Thursday, December 1, 1994 at:

CEBAF
User Liaison Office, Mail Stop 12 B
12000 Jefferson Avenue
Newport News, VA 23606

Proposal Title

Search for Direct Conversion of Electrons into Muons

Contact Person

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Experimental Hall: C* **Days Requested for Approval:** 2

Hall B proposals only, list any experiments and days for concurrent running:

* Hall A would be OK, too.

CEBAF Use Only

Receipt Date: 12/15/94 94-114

By: JP

$e \to \mu$ 12/14/94

LAB RESOURCES REQUIREMENTS LIST

CEBAF Proposal No.: ______________________ (For CEBAF User Liaison Office use only.) Date: ______________

List below significant resources — both equipment and human — that you are requesting *from CEBAF* in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments, such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

***Major Installations** (either your equip. or new equip. requested from CEBAF)*

μ detector (under design)

New Support Structures: ______________

Data Acquisition/Reduction

Computing Resources: ______________

New Software: ______________

Major Equipment

Magnets ______________

Power Supplies ______________

Targets ______________

Detectors ______________

Electronics ______________

Computer Hardware ______________

Other ______________

Other

____

e →μ 12/14/94

HAZARD IDENTIFICATION CHECKLIST

CEBAF Proposal No.: ______________________ Date: ______________
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Hall C or A spectrometer system with
10 cm lqd. H2 target

Check all items for which there is an anticipated need.

Cryogenics
- ____ beamline magnets
- ____ analysis magnets
- ____ target
- type: ________
- flow rate: ________
- capacity: ________

Electrical Equipment
- ____ cryo/electrical devices
- ____ capacitor banks
- ____ high voltage
- ____ exposed equipment

Radioactive/Hazardous Materials

List any radioactive or hazadorous/toxic materials planned for use:

____
____
____
____

Pressure Vessels
- ____ inside diameter
- ____ operating pressure
- ____ window material
- ____ window thickness

Flammable Gas or Liquids
- type: ________
- flow rate: ________
- capacity: ________

Drift Chambers
- type: ________
- flow rate: ________
- capacity: ________

Other Target Materials
- ____ Beryllium (Be)
- ____ Lithium (Li)
- ____ Mercury (Hg)
- ____ Lead (Pb)
- ____ Tungsten (W)
- ____ Uranium (U)
- ____ Other (list below)

____
____

Vacuum Vessels
- ____ inside diameter
- ____ operating pressure
- ____ window material
- ____ window thickness

Radioactive Sources
- ____ permanent installation
- ____ temporary use
- type: ________
- strength: ________

Large Mech. Structure/System
- ____ lifting devices
- ____ motion controllers
- ____ scaffolding or
- ____ elevated platforms

Lasers
- type: ________
- wattage: ________
- class: ________

Installation:
- ____ permanent
- ____ temporary

Use:
- ____ calibration
- ____ alignment

Hazardous Materials
- ____ cyanide plating materials
- ____ scintillation oil (from)
- ____ PCBs
- ____ methane
- ____ TMAE
- ____ TEA
- ____ photographic developers
- ____ other (list below)

____
____

General:

Experiment Class:
- ____ Base Equipment
- ____ Temp. Mod. to Base Equip.
- ____ Permanent Mod. to Base Equipment
- ____ Major New Apparatus

Other: ________
____

e → μ 12/14/94

BEAM REQUIREMENTS LIST

CEBAF Proposal No.: ______________________________ Date: ____________________
(For CEBAF User Liaison Office use only.)

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition #	Beam Energy (MeV)	Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Target Material Thickness (mg/cm^2)
1	300	$< 60\ \mu A$	$>$ 40% polarization, if possible/	10 cm lqd H_2	
2	4000	$< 60\ \mu A$	$>$ 40% polarization, if possible/	10 cm lqd H_2	

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. For 1995, E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Starting in 1996, in an evolutionary way (and not necessarily in the order given) the following additional values of E_{Linac} will become available: E_{Linac} = 400, 500, 600, 700, 900, 1000, 1100, and 1200 MeV. The sequence and timing of the available resultant energies, E_{Beam}, will be determined by physics priorities and technical capabilities.

RESEARCH PROPOSAL TO CEBAF

Search for Direct Conversion of Electrons into Muons

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Boston, Massachusetts 02115

W. Oliver
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and others

Abstract

We propose to search for the lepton number violating reaction: $e^- + p \rightarrow \mu^- + X$ where M_X is in the range: $M_p < M_X < M_p + 1250$ MeV. The highest sensitivity will occur when X is a narrow state, lepto-proton, produced in association with a μ^-. The proposed experiment will extend the search for lepton number violation well beyond the limits of previous experiments by probing for new mechanisims. Longitudinally polarized electron beams, if available, at .3 GeV and 4. GeV will be used. To search for $e^- + p \rightarrow \mu^- + X$ the Hall C HMS spectrometer, at an angle of 12.5°, will scan μ^- momenta corresponding to $M_p < M_X < M_p + 1250$ MeV for the 4. GeV beam and $M_p < M_X < M_p + M_\pi$ for the .3 GeV beam. (The spectrum of M_X could be a continuum and/or have well defined peaks.) Along with the measurements of the mass spectra, the beam polarization will be used to search for evidence of parity violation in the μ^- production. The detection of parity violation, even without a detailed understanding of the level of the backgrounds, would (by itself) be

evidence for a new type of interaction beyond the "Standard Model,"[1] since all expected backgrounds do not violate parity.

For the .3 GeV beam, an indicator of the sensitivity of the experiment (for detecting a narrow lepto-proton) is the ratio, R_B, of background μ^-s, upper limit, to detected elastic ep scattering. At 54^o, an upper limit for R_B of $R_B \approx 1\times10^{-6}$ has been shown to be achievable at Bates. Thus, in the proposed experiment direct conversion cross sections should be observable with a sensitivity much greater than $\sigma(\mathrm{ep} \to \mu\ \mathrm{x}) \geq 1\mathrm{x}10^{-6}\sigma(\mathrm{ep} \to ep\ )$ for $\mathrm{M_p} < \mathrm{M_x} < \mathrm{M_p} + \mathrm{M_\pi}$. For $\mathrm{M_p} < \mathrm{M_x} < \mathrm{M_p} + 1250\ \mathrm{MeV}$, at 4. GeV, the calculations are still being refined, but indicate a sensitivity of better than:
$\sigma(\mathrm{ep} \to \mu\ \mathrm{x}) \geq 1\mathrm{x}10^{-5}\sigma(\mathrm{ep} \to ep\ )$.

Requests: The Hall C HMS spectrometer operated for high resolution with muon detection. Longitudinally polarized beams, if available, of 60 μA at .3 and 4. GeV, each for 24 hours. 10 cm liquid hydrogen target. (This experiment might be run simultaneously with the proposed experiment: "Search for Narrow Excited States of the Proton.")

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* Spokesperson (Garelick@NEU.EDU, 617 373 2936)

Motivation

The most sensitive searches for μ-->e conversion are:[2] μ− Ti-->e− Ti (μ− conversion in the field of a Titanium nucleus) and the search for the decay $\mu^+ \to e^+\gamma$. However, these decays could be forbidden if μ-->e conversion is mediated by a lepto-boson carrying both e and μ quantum numbers which converts one of the nucleons to a lepto-nucleon. (The term lepto is used to indicate an object with non zero lepton number.) This possibility provides a strong motivation for the proposed experiment. For example, in this view, the reaction μ− Ti-->e− Ti would be forbidden but the reaction μ^- Ti-->e^- lepto-Ti would be allowed. If the [(lepto-Ti) -(Ti)] mass difference is greater than about 20 MeV, such a conversion process would have, to date, been missed in all previous Ti type experiments. In the proposed experiment, the recoiling nucleon system (lepto-proton) is allowed to have masses, M_X, in the range: $M_p < M_X < M_p + 1250$ MeV. The spectrum of M_X could be a continuum and/or have well defined peaks. We do not know of any previous experiment that directly investigated the proposed reaction mechanism.

Polarized electron beams will be used to search for evidence of parity violation in the μ^- production. The detection of parity violation, even without a detailed understanding of the level of the backgrounds would (by itself) be evidence for a new type of interaction beyond the "Standard Model." All expected backgrounds do not violate parity. (This could be checked, in part, by measuring μ^+ s.)

Experimental Plan

Longitudinally polarized electron beams at .3 and 4. GeV will be used. The HMS spectrometer, at an angle of 12.5^{o}, will scan μ^- momenta corresponding to $M_p < M_X < M_p + 1250$ MeV for the 4. GeV beam and $M_p < M_X < M_p + M_\pi$ for the .3 GeV beam in order to detect the reaction of interest, $e^- + p \rightarrow \mu^- + X$. The kinematics for this reaction are given in Figs. 1 and 2. For μ^- identification, we will require that the particle detected at the HMS focal plain does not produce an electromagnetic shower (is not an electron) for the .3 GeV experiment and for the 4. GeV experiment does not interact in a thick absorber (is not a π.) (The design of this μ identification system is still in progress, but it is presently planned for the 4. GeV experiment that tracking chambers will be used to follow the μ s as they pass through the absorber.) Some results from Bates, using just a "NOT electron" signature from a gas Cerenkov counter, are shown in Figs. 3 and 4. For the 790 MeV data, most of the "NOT electron" signal is probably from π s. At 290 MeV the "NOT electron" signal is probably from Cerenkov counter inefficiency.

Sensitivity of the Experiment
Beam energy = 300 MeV

The dominant source of background is expected to be μ^-s from the decays $\pi^- \rightarrow \mu^- + \upsilon$. At the beam energy of 300 MeV, background from the reaction $e^- + p \rightarrow e^- + p + \pi^- + \pi^+$ should be zero for the chosen kinematics. The main anticipated backgrounds are from: 1) Electrons which are misidentified and appear as μ s. 2) $\pi^- \rightarrow \mu^- + \upsilon$ where the π^- is produced from neutrons in the target walls. 3) π^- s which appear as μ^- s. (The π^-, μ^- separation is still under study.)

The sensitivity is determined in large part by the backgrounds labeled 1) through 3), above. We estimate that background 2) will be much smaller than 1), as a result of identifying μ s that come from the target end windows, using standard spectrometer tracking techniques. Concerning background 1), our estimate, from the experience of others at Bates, is that the electron rejection in the μ signal of 10^4 can be achieved. The calculated sensitivity ratios eμ/ep determined using a 10^2 larger, 1%, electron misidentification are plotted versus M_x for the 300 MeV beam in Figs. 5. (Additional details can be found in the proposal: "Search for Narrow Excited States of the Proton," which might be run simultaneously.)

Considering setup time, etc., a total of 24 hours at this beam energy, should be sufficient.

Sensitivity of the Experiment
Beam energy = 4. GeV

Calculations of the sensitivity at this energy are still being carried out. However, the sensitivity ratios eμ/ep determined by assuming a total background of 1% of the electron rate have been done. The results are given in Fig. 6. (Additional details can be found in the proposal: "Search for Narrow Excited States of the Proton," which might be run simultaneously.)

Considering setup time, etc., a total of 24 hours at this beam energy, should be sufficient.

Search for Parity Violation

The principle is that backgrounds: μ s from π decay and electrons come from interactions of the beam and the target(s) which obey parity. Thus, an longitudinal polarization asymmetry dramatically above that expected from the weak interactions, about 10^{-6}, will indicate a new type of interaction.

For the purpose of making estimates of the asymmetry, A, in the cross sections, for the two longitudinal beam polarizations (+, -): $A = \frac{(N_+ - N_-)}{P\,(N_+ + N_-)}$, where P is the polarization of the beams and the N s are the number of events measured with each of the polarized beams. It follows that the fractional uncertainty in the measurement of A is: $\frac{\delta A}{A} = \frac{1}{P\,A\,\sqrt{N_+ + N_-}}$. For P = 40%, A =1, $N_{total} = N_+ + N_- = 625$ detected μ s, $\frac{\delta A}{A} = 10\%$. If the lepton number violating reaction, e-->μ, takes place at a significant level with respect to the backgrounds and it has a large parity violation, a new interaction beyond the "Standard Model" could "easily" be discovered.

References

1) For example: D. J. Griffiths, Introduction to Elementary Particles, John Wiley & Sons, Inc. (1987)

2) Particle Data Group, Phys. Rev D50 (1994)

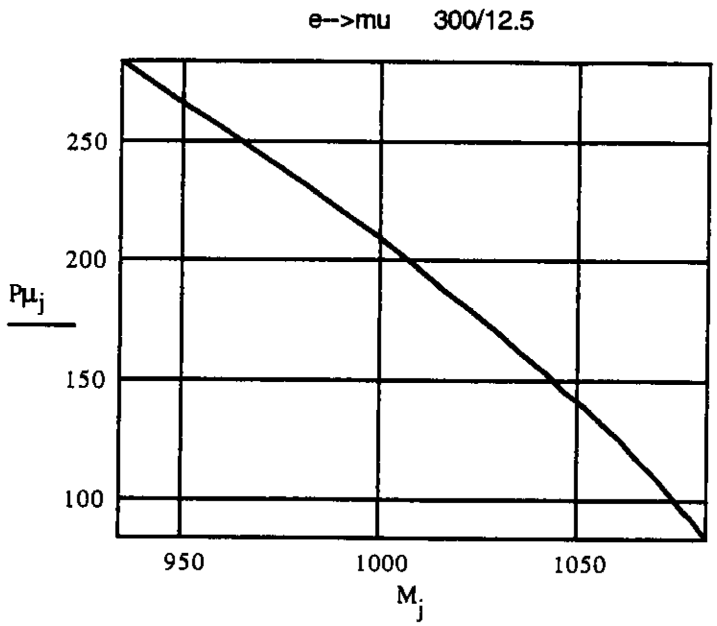

Fig. 1. $P\mu_j$ is the μ's momentum (MeV/c), and M_j is the mass of the X system (MeV) in ep->μX for the .3 GeV experiment.

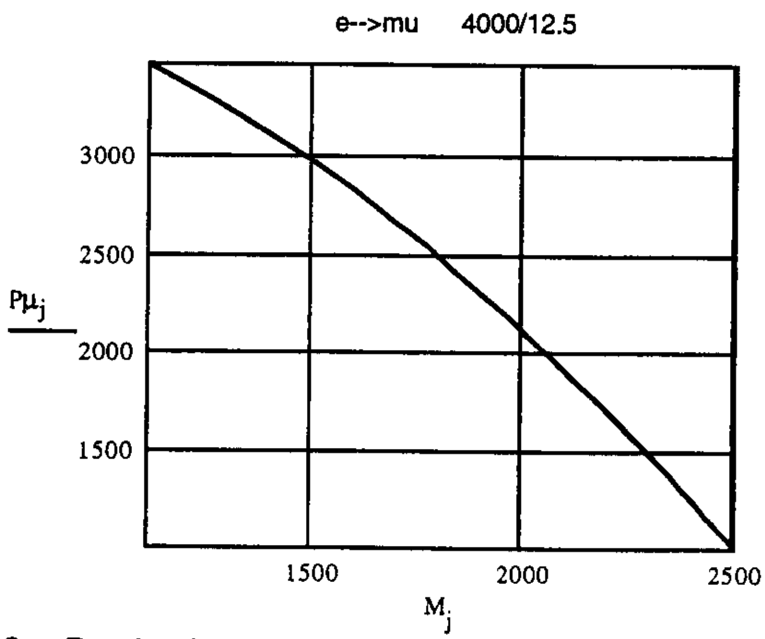

Fig. 2. $P\mu_j$ is the μ's momentum (MeV/c), and M_j is the mass of the X system (MeV) in ep->μX for the 4. GeV experiment.

Fig. 3. Results from Bates at 290 MeV and 54°. The radiative tail (calculation) and the measured electron cross section and the (NOT electron)/electron ratio are plotted. (log plot)

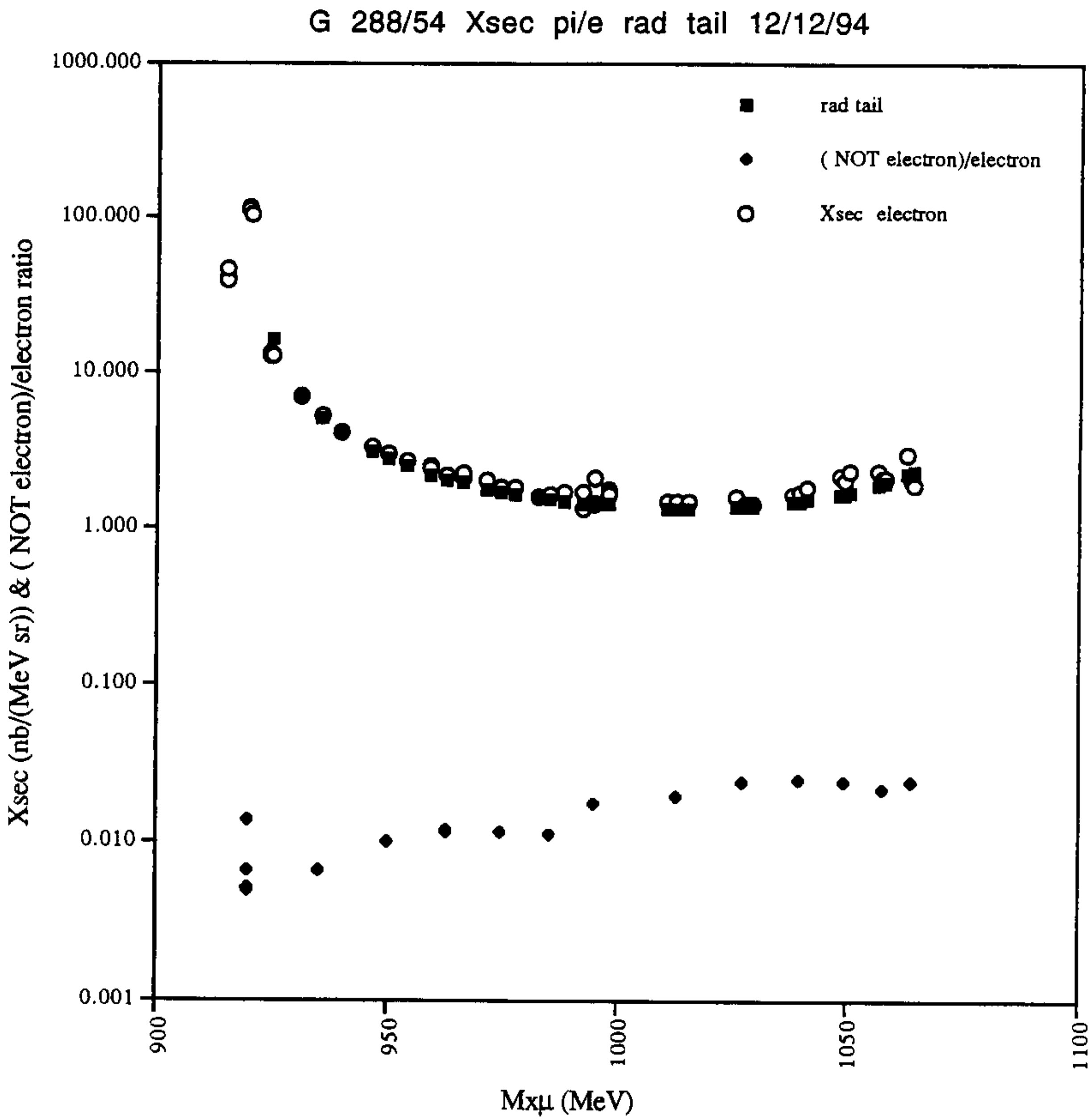

Fig. 4. Results from Bates at 790 MeV and 54^{o}. The electron and NOT electron cross sections as well as the calculated radiative tail are plotted. The N*(1236) is very evident. The NOT electron cross section is a mixture of: misidentified electrons, π s and μ s. (log plot)

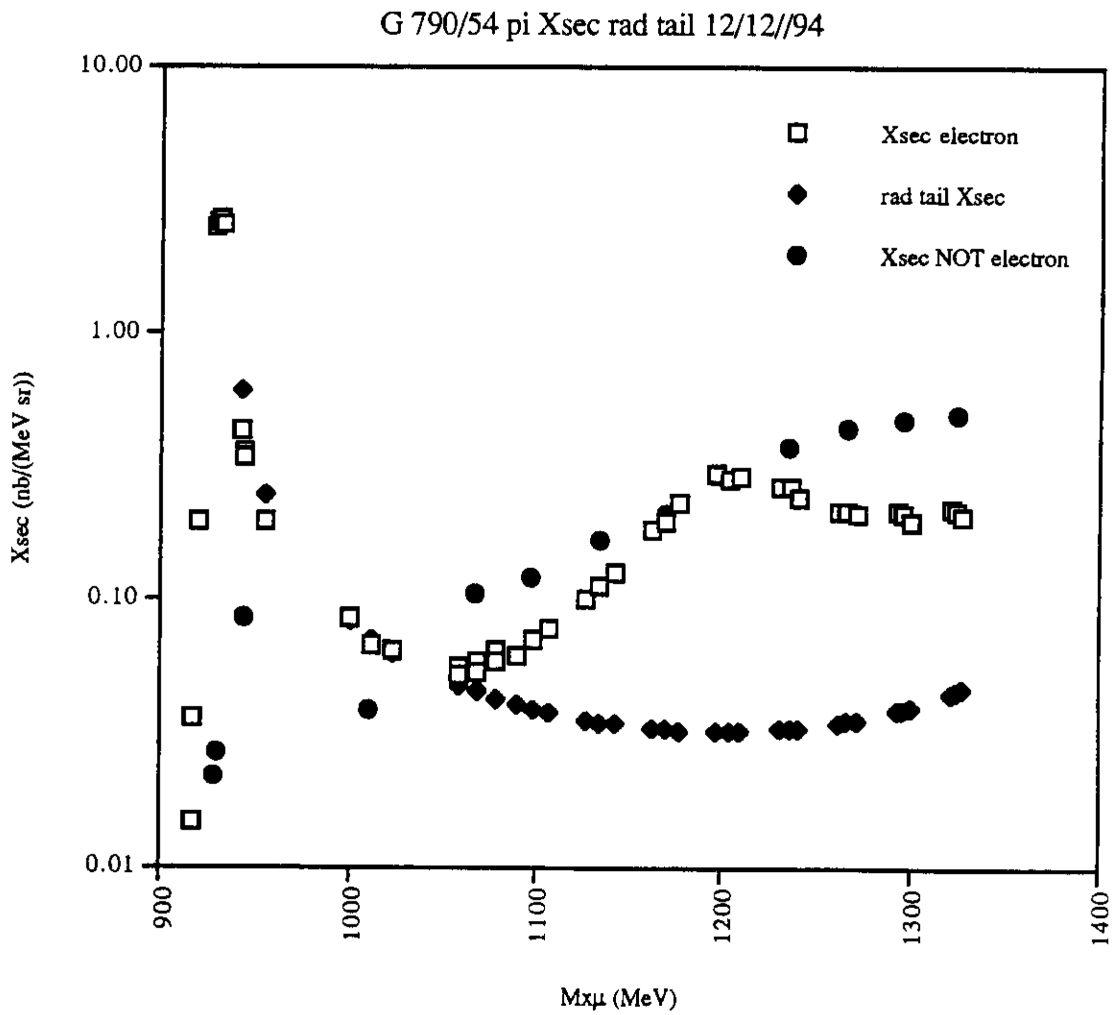

Fig. 5. Sensitivity of the .3 GeV experiment. S_j is the cross section sensitivity, 5 std/ 5% signal (ep->μX)/(ep->ep). M_j is the mass (MeV) of the narrow X system in ep->μX.

$$\text{Xotot} := \text{Xin} + \text{Xout} + 1.5\cdot\frac{1}{137\cdot 3.14}\cdot\left(\ln\left(\frac{Q^2\cdot 10^6}{.260}\right)-1\right) \qquad \text{Xotot} = 0.047$$

$$\Gamma_j := \Gamma\text{total}_j \qquad \text{Xo} := \text{Xotot}$$

$$R_j := \Gamma_j\cdot\frac{\text{Xo}}{2}\cdot\left(\frac{1}{\text{Ef}-E_j}\right)\cdot\left[\left(\frac{\text{Ef}}{E_j}\right)^2+1\right]$$

Note, R_j is the probability, per elastically scattered electron, of the degraded electron ending up in in the bin R_j.

$$S_j := R_j\cdot 10^{-2}$$

Beam energy = 300 MeV 12.5 degrees 1.0 % of radiative tail.

Sj is the the cross section sensitivity, 5 std/5.0% signal (e-->mu) / (ep-->ep).

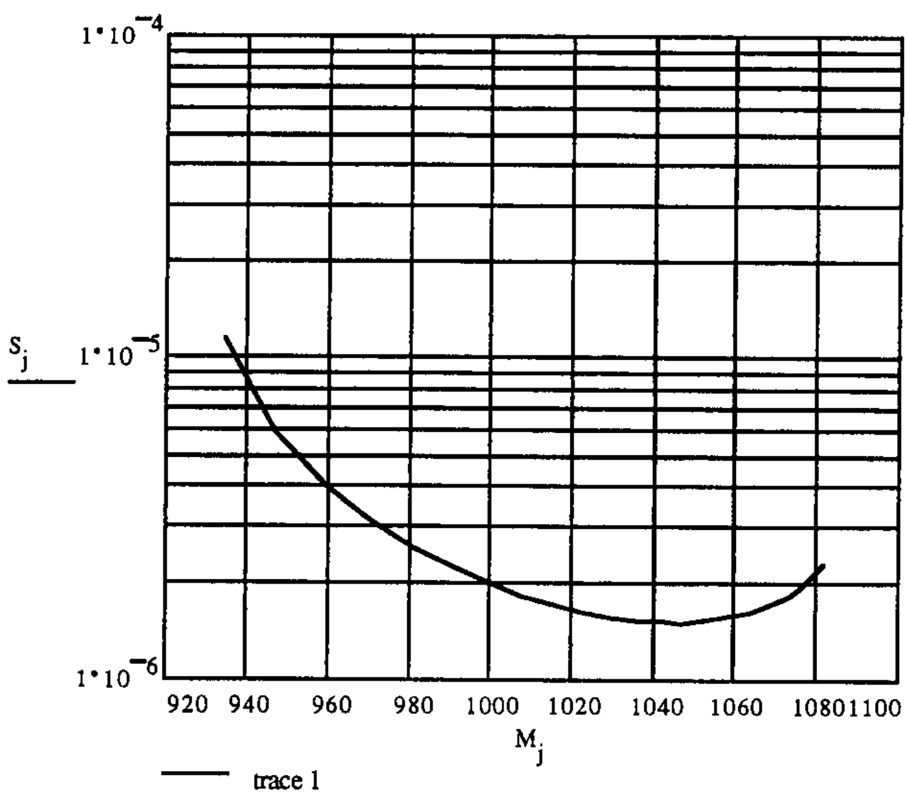

Fig. 5. Sensitivity of the 4. GeV experiment. SS_j is the cross section sensitivity, 5 std/ 5% signal (ep->μX)/(ep->ep). M_j is the mass (MeV) of the narrow X system in ep->μX.

$\Gamma_j := \Gamma total_j$ 4000/12.5 e-->mu

$$RR_j := \frac{\Gamma_j}{270}$$

$$SS_j := .05 \cdot .01 \cdot RR_j$$